REPORT 76-003-7736

CONTROL OF SUBBASE COMPACTION

A FINAL REPORT

September, 1975

Prepared By

DONNA TROIANO

The New Jersey Department Of Transportation

Division Of Research And Development

In Cooperation With

The U.S. Department Of Transportation

Federal Highway Administration

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16. Abstract

The Test Strip Method which is based on the use of nuclear moisture-density gages has been proposed to replace the current "method" specification for soil compaction control in New Jersey. This research was initiated to determine the feasibility and desirability of adopting the proposed method for New Jersey subbases. For each of the three years of this study, density measurements were collected from projects using the present specifications and several projects were selected for simulated application of the proposed method. This simulation revealed that while the proposed Test Strip Method yields improved subbase compaction compared to the current method, neither method consistently achieves 100 percent of the standard Proctor density which is generally considered necessary to prevent the pavement distress associated with further compaction under traffic. If the proposed procedure includes both the Test Strip and follow up acceptance testing a considerable amount of field work is required. The amount of work involved can be substantially decreased by eliminating the schedule of follow-up testing and in essence using the Test Strip results only to produce an improved "method" compaction procedure.

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CONTROL OF SUBBASE COMPACTION: FINAL REPORT

1.0 INTRODUCTION:

This report presents the results of a three-year study designed to determine the applicability to New Jersey conditions of a method of soil compaction control referred to as the "Test Strip Method."

2.0 BACKGROUND:

2.1 Existing Specification for Compaction Control:

New Jersey presently employs a method specification for controlling compaction of granular subbase. Under these provisions a minimum of 5 passes per lift is required for "approved" pneumatic tire rollers and a range of 2 to 5 passes per lift is specified for "approved" vibratory rollers. Lift thicknesses are not to exceed eight inches. These requirements do not change regardless of the total thickness, type or source of subbase materials.

The exact number of passes to be used with a particular subbase material and roller is determined by the Project Resident. The choice of passes and the adequacy of the resulting compaction is thus a function of the Resident's knowledge of equipment and material and the extent of any (optional) density tests performed.

The moisture content of the subbase material at the time of compaction is also a matter of engineering judgment. There is no defined criteria for moisture in the present specification. It is the engineer's responsibility to determine if the moisture content is either excessive or deficient to produce satisfactory compaction and to undertake appropriate remedial measures. At one time, however, New

Jersey had a specification which required the moisture content to be within two percentage points of optimum during compaction. This requirement was later dropped because it was not being enforced.

2.2 Laboratory Compaction Standards:

Once a roller pass requirement is set for subbase on New Jersey projects, no sampling of the density subsequently achieved is required.*

In marked contrast, nearly all states compare field compaction results to a laboratory standard. As might be expected, however, there is no single test which is accepted by all. According to a 1973 NCHRP report (11),** of the many density tests available as a standard, the two used most often are the standard Proctor (ASTM D698 or AASHO T-99) and modified*** Proctor (ASTM D1557 or AASHO T-180) (3, 12).

Various agencies have conducted studies to determine the degree of subbase compaction required during construction to prevent further densification under traffic. For this work some agencies, including the New Jersey Department of Transportation, removed the surfaces of in-service roads and compared the field density of the underlying soil with the achievable standard Proctor. Other agencies have investigated the relationship between the amount of pavement

*In small areas where hand compactors must be used, a minimum of 95% of standard Proctor density is required, conformity being based on the results of the sand-cone method of measurements.

**The numbers in parenthesis indicate the appropriate references for the information given. References are listed on page 38.

***The modified Proctor uses a greater compactive effort and thus yields a greater density.

deflection under traffic and the degree of compaction in the subbase. All these studies proved a need for a minimum density of 100 percent of the standard Proctor for optimum road performance. (4, 5, 6, 9, 11)

Further, nearly half of the states require a minimum of 100 percent of the standard Proctor density in their subbase specifications (11, 13). In the event of a non-conformity, these states require recompaction or removal and replacement depending on the severity of the deficiency. (2)

Similarly, one-fourth of the states require that the moisture content be near the laboratory optimum during rolling. Implicit in this approach is that the compactive effort in the field is comparable to that in the laboratory.

Fifty percent of the states specify moisture content in terms of an end result (11, 14). That is, essentially any water content is permitted providing that the given percentage is appropriately matched with the compactive effort to achieve the desired density. This approach reflects the well-known relationship illustrated in Figure 1. As indicated, an increase in compactive effort applied to a given soil will result in a decrease in the optimum moisture content needed to achieve optimum density. In the field such changes in compactive effort result from varying the number of passes or the size, weight, or frequency and amplitude of a vibratory roller or the weight, tire pressure, or contact area of a pneumatic roller.

It is important to note, however, that while various combinations of moisture and compactive effort can be employed to yield a given density, these combinations can entail varying soil behavior with

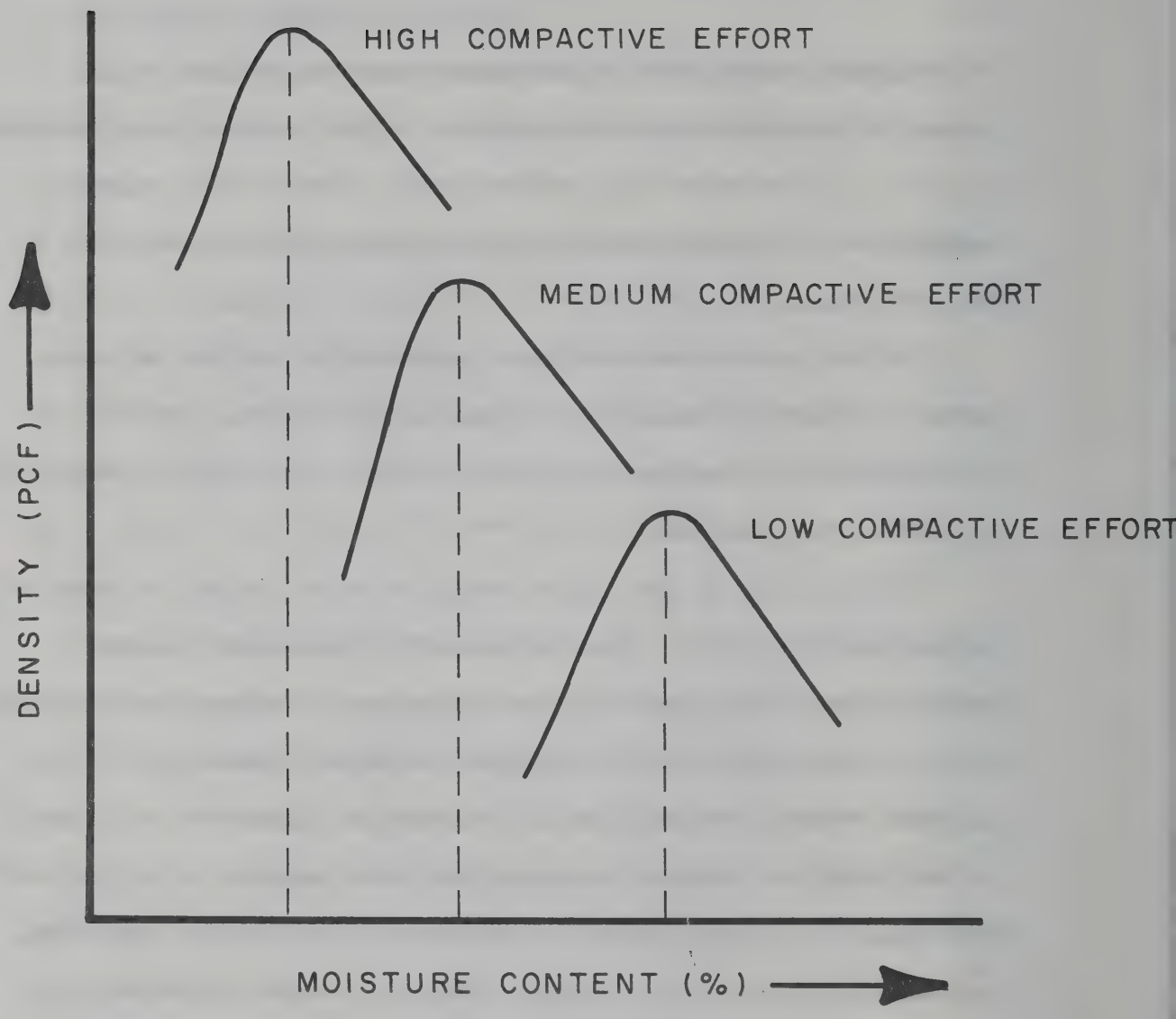

Figure 1: Relationship Between Compactive Effort And Optimum Moisture.

respect to strength and swelling potential (1). The most stable road support will prevail if one combination of factors is selected and maintained.

Many agencies emphasize the fact that using a Proctor density standard is correct only when the material tested in a laboratory is identical to the field material. That is, changes in material gradation can significantly change the density. For example, Figure 2 illustrates how the achievable Proctor for various materials changes with the relative fraction of "coarse" (plus number 4 sieve) size material.

To properly apply an end result density requirement, then, it is necessary to continually monitor the reference value as the gradation changes. Two methods for accomplishing this would be to perform a new Proctor test on the new field materials in conjunction with the family of curves (one point Proctor) or to establish and use a gradation density relationship such as that previously shown in Figure 2. A third method involves using a relationship between loose and compacted void ratios such as that shown in Figure 3. A recent report proposes this last procedure as a relatively simple method for determining the density achievable at a specific gradation (10). By entering the graph of Figure 3 with the loose void ratio, the achievable Proctor density can be calculated from the corresponding compacted void ratio and the specific gravity of the sample. The reported advantages of this method are that the loose void ratios are rather quick and simple to determine and encompass a wide variety of possible gradation changes on all of the specified sieves.

2.3 Nature of the Test Strip Control Method:

The Test Strip Method under investigation is a modification of the density control system developed by the State of Virginia and is based

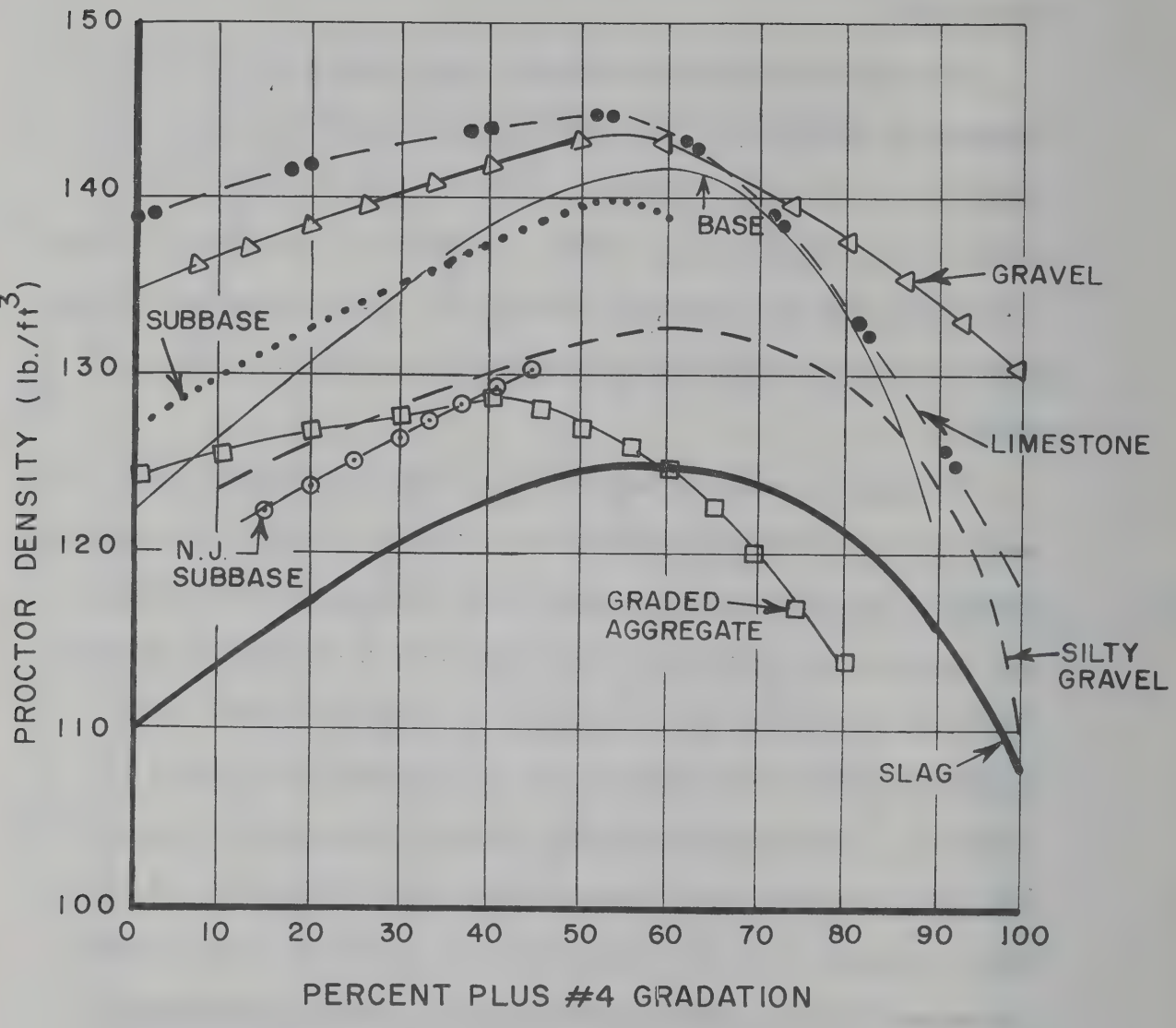

Figure 2: Influence Of #4 Gradation On Proctor Values For Different Types Of Materials (From Ref. 7,8,15,17)

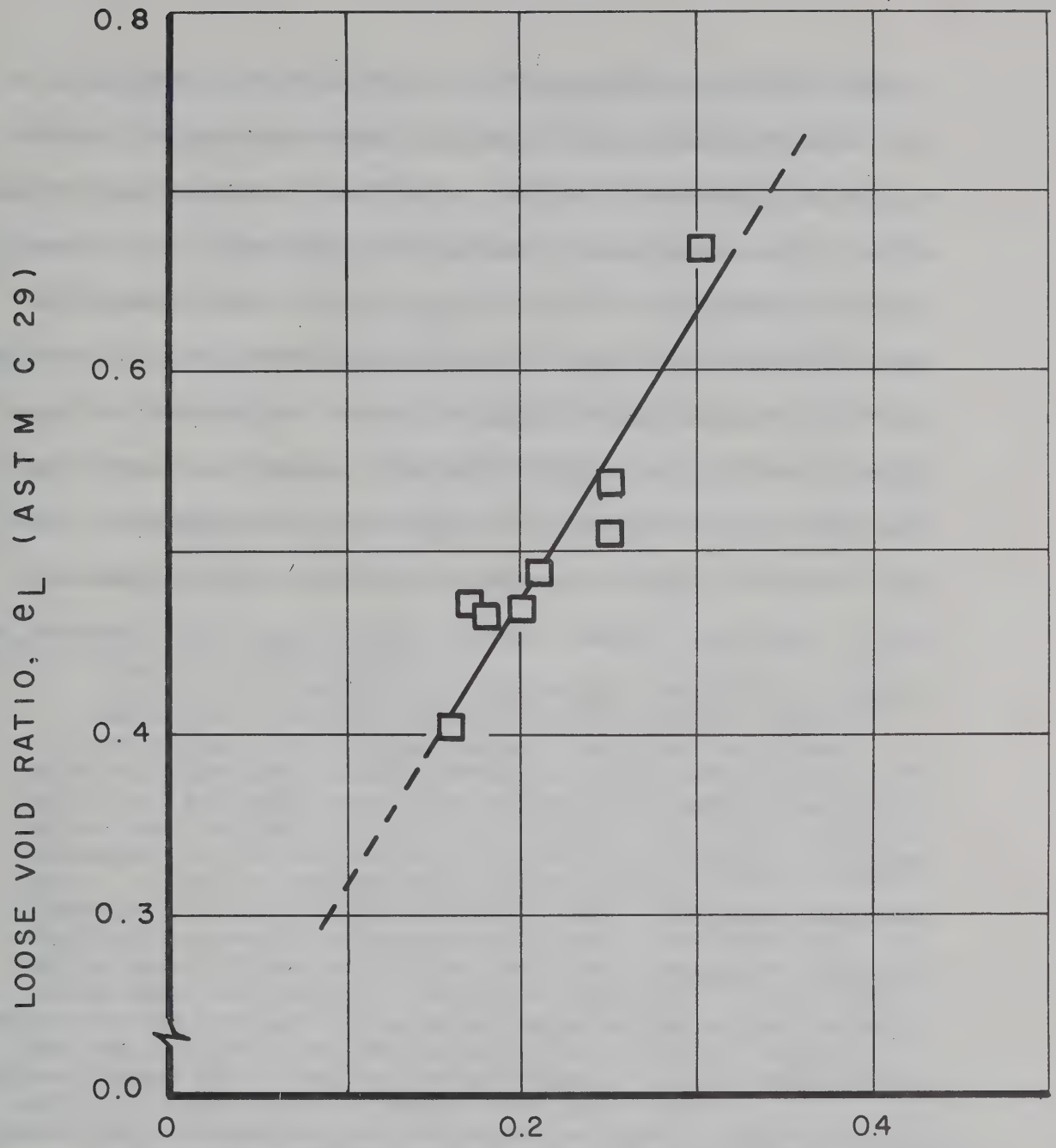

Figure 3: Relationship Between Compacted Void Ratio (ASTM D 1557 Effort) And Loose Void Ratio (ASTM C 29). (From Ref. 10)

on the use of nuclear devices. (2) The "Test Strip" referred to in this metnod is simply a small area of subbase on a project on which nuclear moisture-density testing is performed after each pass of the roller. The maximum density obtained from this Test Strip is related to a laboratory test and if adequate provides a standard for controlling the compaction of other sections of the project which are built with the same materials and equipment. In practice, this requires subdividing the project into small sample areas known statistically as "lots" of subbase. Changes in the variables used in the Test Strip will require a new density standard (i.e., a new Test Strip). Variables that may change include subbase lift thickness, source of material, rollers, and gradation variations.

Based on a consultant's recommendation, this Department's specification group proposed that New Jersey adopt the Test Strip Method as a standard for controlling compaction of both subbase and embankment materials. The initial consultant's proposal had two alternate procedures - one using the optimum density from the Test Strip as the standard by which to judge the remainder of the project and the other using a standard laboratory test as the target density for the project. These two procedures are considered in the present research with the major effort being devoted to the former.

A third alternate has recently been incorporated in the final draft of the forthcoming revised Department standard specifications for 5 of 6 types of New Jersey subbase.* In this most recent proposal

*The general gradation and composition requirements for New Jersey subbases are presented in Appendix C, page 49 .

a Test Strip is performed only for the purpose of enabling the Project Resident to make an informed choice of the number of passes to be made by the roller. The Test Strip density is not compared to a laboratory standard nor is any follow-up acceptance testing required. For the Type 5A material, used exclusively under flexible pavements, however, the Test Strip Method is to be used inclduing follow-up densities but excluding any comparisons to laboratory standards. Although this particular use of the Test Strip Method was not included in the present research, comments on its adequacy will be offered later in the report.

3.0 NUCLEAR TESTING EQUIPMENT:

New Jersey presently uses seven nuclear density gages for soils and bituminous testing, several of which were used to collect the moisture and density data for the first half of this research study. All of the devices were purchased from Troxler Electronic Laboratories, two being the older 1401 models and the other five are the newer 2401 models. During the second half of the study, data was obtained almost exclusively with a model 2401 gage acquired by the Division of Research and Development.

All Department gauges are calibrated yearly on standard blocks. The moisture calibration range is from 0 to 40 pcf (pounds per cubic foot) in 0.25 pcf increments while the density calibration range is from 70 to 160 pcf in 0.5 pcf increments.

Analysis of the available calibration data for the various nuclear gages used in the early stages of the work indicates that the maximum uncertainty (95% confidence level) associated with a

single measurement is 3.75 pcf for density* and 1.0 pcf for moisture.

In the particular case of the Research Division's gage, the corresponding 95% confidence level uncertainty is 1.47 for density measurements. In the moisture mode Research's gage is accurate within 0.75 pcf.

The above described measurement tolerances associated with New Jersey nuclear gages are within the allowable guidelines set forth by ASTM D 3017 and D 2922.(3). Further, the measurement uncertainty associated with the majority of the readings in this work was generally further reduced by averaging two readings.**

4.0 RESEARCH APPROACH:

This research was divided into a laboratory phase and two concurrent field phases. A discussion of the nature of each of these phases and a summary of work accomplished follows.

4.1 Field Studies of the Current Control Method:

The first field phase was directed toward determining the level of subbase compaction being achieved by the current method specification and thus in essence answering the question "How well are we currently doing?" The procedure involved here was simply to obtain the average of five random nuclear density readings taken in an area of subbase recently rolled where the number of passes had been established by the

*Applies to direct transmission mode of measurement, used exclusively in this work.

**In general,

$$\sigma_{\bar{x}} = \sigma/N$$

where $\sigma_{\bar{x}}$ = Standard error
σ = Standard deviation
N = Number of measurements

Project Resident. Twenty-one sets of these readings have been collected from 15 projects, along with the corresponding standard Proctor for each project material.

4.2 Field Studies of the Test Strip Method:

The second, major, field phase was directed toward answering the question "How well will the Test Strip Method adapt to New Jersey conditions?" Toward this end, fourteen projects under construction were selected to simulate the proposed Test Strip specification. In this phase of the work, an area of mainline subbase freshly placed and graded was set aside at the beginning of the project for the Test Strip. Then each time the roller made a pass over the area five nuclear density readings were taken. The average density of the five readings was plotted against the number of passes to form a graph. The optimum density and corresponding optimum number of passes was then determined from this graph. These values were appropriate only for similar circumstances on that project.

On the majority of the projects selected for application of the Test Strip Method, five follow-up density readings were taken on each "lot" or area of mainline having the same conditions as the original Test Strip. These subsequent test "lots" varied in length from 300 feet to 800 feet. The average of the five readings from each lot was then compared with the standard densities determined by laboratory and field tests. Lot data was collected on ten of the fourteen projects selected. The number of lots varied from one to eleven on each project.

4.3 Laboratory Studies of Density Standards:

In addition to the field testing on the Test Strip, three different laboratory density tests were performed on material taken from that area in an attempt to establish an appropriate density standard to which the Test Strip optimum density could be compared. These laboratory tests included the two general Proctor methods (ASTM D698 Method C and ASTM D1557 Method D) and a Relative Density test (ASTM D2049). This latter test uses vibration as the compactive effort instead of impact as the other two methods do.

A special series of Proctors was run on 3 different subbase types to verify that changes in New Jersey soils gradations (on the #4 sieve) produce corresponding changes in Proctor densities. The soil samples tested were held within specification limits on all other sieves while the percent passing the number four sieve was allowed to vary throughout its specified range.

Specific gravity tests were performed on the coarse and fine portions of two different subbase types to try to detect any differences that might influence Proctor results.

In addition to the field and laboratory test data mentioned, roller information and material gradations were recorded for all tests on conventional and Test Strip projects. Data was also gathered from the files to determine the typical characteristics of subbase on current projects, i.e., gradation, thickness, and source variability.

5.0 RESULTS AND DISCUSSION:

The results reported after the first year's study were verified in the following two years of research. All types of subbase

were included in this analysis. Therefore, it is felt that the results may be generally applied to all New Jersey subbases.

5.1 Projects Controlled by Present Method Specification:

The twenty-one sets of readings gathered on projects controlled by the present method specification are listed in Table 1. As indicated, the measured field density on these projects ranges from 81.1 to 100.6 percent of the standard Proctor and averages 92.5 percent. Only two of the measured field densities reached the 100 percent Proctor level indicated in the literature as necessary for optimum performance of the roadway structure.

It is to be noted, however, that as in any testing process, there is variability in field and laboratory density measurements. Thus, while most of the field densities were indicated to be lower than the corresponding standard Proctor, the inherent testing variability must be taken into consideration to determine if these apparent differences are indeed real. The results of a statistical significance test (the student's "t" test performed at the 95% confidence level) are shown in Table 1. These tests indicate that the apparent "low" level of density is, in fact, significant. That is, 17 of the 21 field densities were significantly lower. Therefore, only two densities which appeared to be lower than the Proctor values were not.

One possible contributing factor to the variability (i.e., standard deviation) of field density measurements is worth noting. That is, these areas were subjected to variable traffic loads during construction at the five randomly selected locations. Some places may have had bulldozers, graders, subbase haul trucks, etc., pass over them while other places were only loosely spread and compacted.

TABLE 1

RESULTS FROM PROJECTS USING PRESENT SPECIFICATIONS

Subbase Type	Aver. Field Density	Standard Deviation s	Standard Proctor	Percent Standard Proctor	Significantly Lower Than Standard Proctor
1B	118.0	3.34	136.9	86.1	Yes
1B	118.7	5.36	123.8	97.4	No
1B	113.9	1.62	123.8	92.0	Yes
1C	123.8	1.36	123.6	100.1	No
1C	107.6	2.05	117.0	91.9	Yes
1C	120.17	1.75	125.8	95.6	Yes
1C	122.25	2.77	127.7	95.7	Yes
1C	90.65	6.39	111.8	81.1	Yes
1C	105.85	0.65	110.1	96.1	Yes
1C	120.67	2.90	129.95	92.9	Yes
1C	125.19	2.70	130.55	95.9	Yes
2A	123.6	3.59	138.1	89.5	Yes
2A	114.5	1.17	125.2	91.4	Yes
2A	120.0	2.71	131.1	91.5	Yes
2A	120.05	1.56	128.4	93.5	Yes
5A	131.8	5.25	131.0	100.6	No
5A	117.6	2.01	144.0	81.6	Yes
5A	133.0	1.38	141.5	93.9	Yes
5A	132.60	1.66	135.5	97.9	Yes
5A	134.20	8.10	140.55	95.5	Yes
5A	117.55	12.16*	132.55	88.7	No

Average = 92.5%

S_{Ave} = 3.26%

Range = 81.1% to 100.6%

*The large standard deviation is the result of two questionable values.

Based on limited testing the density differences between areas with construction traffic and those without can average around 5% of the standard Proctor density. Although the data collected is not sufficient to determine the exact amount of compaction resulting from construction traffic it does indicate that traffic has an important influence on compaction. For this reason the proper timing of any acceptance lot testing is essential.

If the testing is performed immediately after rolling but before construction traffic, the State's risk of accepting minimum level work is reduced because generally the densities will be later increased by traffic. On the other hand, the Contractor's risk of failing acceptance testing is reduced if testing is performed after construction traffic has increased the density. In conjunction with this latter procedure, however, the variability of the densities across the roadway due to uneven traffic distribution must also be taken into consideration since such variability results in non-uniform pavement support. If statistically based acceptance procedures are used, the increased variability would be taken into account and the contractor may, in reality, receive no benefit from traffic in regard to achieving acceptance of his work. This is especially true for the upper layers of subbase where acceptance testing has been proposed for the new standard specification (Type 5A subbase).

5.2 Projects Employing Test Strip Method:

5.2.1 Comparison of Test Strip Densities to Laboratory Densities:

The fourteen sets of density values from the projects employing the Test Strip Method are listed in Table 2. Only three of the Test Strips had a measured density equal to or exceeding the standard Proctor.

TABLE 2

TEST STRIP RESULTS

Project Number	Subbase Type	Test Strip Maximum (pcf)	Standard Deviation s	Standard Proctor (pcf)	Percent Standard Proctor	Significantly Lower Than Standard Proctor
1	1A	136.51	3.66	134.15	101.8	No
2	1A	126.21	3.19	133.7	94.4	Yes
3	1B	121.15	3.32	127.50	95.0	Yes
4	1B	132.40	2.71	130.60	101.4	No
5	1C	134.97	2.02	136.25	99.0	No
6	1C	130.46	1.91	133.25	97.8	No
7	1C	117.22	2.06	123.85	94.7	Yes
8	1C	110.10	4.79	125.57	87.7	Yes
9	1C	131.20	0.57	131.80	99.5	No
10	1C	123.65	2.80	129.7	95.3	Yes
11	1C	104.75	2.54	104.7	100.0	No
12	1C	129.25	2.43	134.0	96.4	Yes
13	5A	119.65	2.00	122.50	97.7	Yes
14	5A	127.55	5.10	136.85	93.2	Yes

Average = 96.7%

S_{Ave} = 2.32%

Range = 87.7% - 101.8%

The same significance test used with Table 1 was also applied to this data. In eight of the fourteen cases the maximum test strip density was significantly lower than the standard Proctor. As will be discussed in a following subsection, in four of the latter cases the moisture was not within the suggested requirement which may have affected the Test Strip maximum density value.

Because of the higher compactive effort specified for the modified Proctor test, the density achievable by this test can be expected to be higher than the density of the standard Proctor test on the same soil. Similarly, the maximum density achievable by the relative density test on the same material is also higher than the standard Proctor density, generally being comparable to the modified Proctor density. (These density results are shown in Table A-1 page 42.) It follows, then, that if 100 percent of the standard Proctor test was not attained with New Jersey conditions, then 100 percent of the other two tests was not attained either.

Even though the standard Proctor and the relative density test methods use different types of compaction, i.e., impact and vibration, a definite relationship was observed to exist between them as described in Appendix A. Because they are correlated the decision to use the standard Proctor density as the target value is based on other considerations. Many states and agencies use the standard Proctor as a target value which makes results easily comparable. The standard Proctor is relatively easy to perform compared to the modified Proctor and involves less expensive and more easily transported equipment than the vibratory relative density test. For both these reasons the standard Proctor is selected from this research as the most reasonable choice for a compaction density standard in New

Jersey.

5.2.2 Comparison of Test Strip Moisture to Laboratory Moisture:

Table 3 presents the average optimum moisture content from the Proctor test and the average moisture content from the Test Strip. The Proctor moistures in percent are converted to equivalent moisture in the pounds per cubic foot (pcf) units measured by the nuclear gage. After making these conversions, a student's "t" test was performed at the 95% level on the values. The amount of moisture in 9 of the 14 Test Strips was within the ±2% range formerly specified in New Jersey. But meeting the moisture requirement did not guarantee attainment of the Proctor density. Importantly, however, in four of the five cases where moisture contents were outside the range (three below and one above) density also proved to be deficient.

Determining the proper amount of water for a Test Strip requires attention to at least three factors.

A. Representative Samples

The material tested in the laboratory prior to the Test Strip may not be representative of the actual material used in the field tests. A non-representative sample would, of course, give a false goal for the moisture content.

B. Measurement Uncertainty

Based on some limited variability testing accomplished in this work (see Appendix B) the standard deviation associated with Proctor optimum moisture contents is on the order of 1%. Thus, any single moisture determination could be as much as ±2% (2σ) from the average of many such determinations. To illustrate the influence of this measurement suppose the material in the Test Strip and Proctor test is similar and the laboratory moisture value is 7.5%. If the field value

TABLE 3

MOISTURE RESULTS FOR TEST STRIPS

		Laboratory Results		Test Strip Method		
Project Number	Subbase Type	Optimum Proctor Moisture Content (pcf)	± 2% of Optimum (Range in pcf)	Moisture Content (pcf)	Moisture is Significantly Outside Range?	Density is Significantly Lower Than Standard Proctor?
1	1A	11.87	9.19 - 14.56	9.94	No	No
2	1A	9.36	7.36 - 11.36	12.25	Yes	Yes
3	1B	12.05	9.50 - 14.60	11.85	No	Yes
4	1B	9.31	6.70 - 11.92	9.46	No	No
5	1C	11.51	8.79 - 14.24	8.63	No	No
6	1C	10.53	7.86 - 13.19	8.74	No	No
7	1C	11.15	8.67 - 13.62	8.77	No	Yes
8	1C	13.10	10.58 - 15.61	9.72	Yes	Yes
9	1C	10.81	8.24 - 13.51	7.77	Yes	No
10	1C	10.38	8.38 - 12.38	9.88	No	Yes
11	1C	16.23	14.23 - 18.23	9.34	No	No
12	1C	11.39	9.39 - 13.39	12.54	No	Yes
13	5A	13.17	10.72 - 15.62	4.75	Yes	Yes
14	5A	11.77	9.03 - 14.51	8.27	Yes	Yes

is 6.0% (within ±2% of 7.5% Proctor Value), then the Test Strip would proceed. However, if a second Proctor test were performed, the moisture content could be as high as 9.0% based on the variability of testing established during this research. If this value had been compared to the 6.0%, the Test Strip would need to have water added. In fact, even if the average of the two Proctor values is considered the field moisture is not within two percentage points of optimum.

C. Units of Measurement

Any measurement with the nuclear gage is in the units of pounds per cubic foot. To convert this value to the percentage basis of Proctor results, it must be related to the density. Suppose that the moisture is checked before the Test Strip is begun and is found to be 10 pcf and the density is 100 pcf then the moisture is 10%. However, if the water content remains constant at 10 pcf and the density increases to 130 pcf after several roller passes, the moisture content appears to have decreased to 7.7%. The initial check could have been within the recommended ±2% but after several passes the percentage would have been outside this range.

5.2.3 Comparison of the Test Strip Densities to the Present Specification:

To answer the question, "Is the density achieved by the Test Strip higher than the present specification density?", a student's "t" test at the 95 percent level was performed. The comparison of the average percent standard Proctor values from Tables 1 and 2 indicate that the densities from the Test Strips are significantly higher than the densities on projects using the present specification.

5.2.4 Comparison of Lot Densities to Test Strip Densities:

Table 4 lists the average densities from each lot measured. Relative to the maximum Test Strip values the lot densities range from

TABLE 4

LOT DENSITY RESULTS

Project Number	Subbase Type	Number of Lots Tested	Percent of Test Strip Achieved			Percent of Standard Proctor Achieved		
			Range	Average	Number of Significantly Low Lots	Range	Average	Number of Significantly Low Lots
1	1A	6	86.8 - 90.8	89.5	6 of 6	88.4 - 92.4	91.1	6 of 6
2	1A	6	101.1 - 103.4	102.1	0 of 6	95.5 - 97.6	96.4	3 of 6
3	1B	2	102.5 - 103.2	102.8	0 of 2	97.4 - 98.1	97.8	0 of 2
4	1B	5	92.9 - 97.0	94.7	5 of 5	94.2 - 98.4	96.0	3 of 5
5	1C	11	87.2 - 100.8	96.2	5 of 11	86.4 - 99.8	95.2	5 of 11
6	1C	5	93.1 - 96.6	95.6	5 of 5	91.1 - 94.5	93.5	5 of 5
9	1C	2	96.3 - 96.6	96.4	2 of 2	95.9 - 96.1	96.0	2 of 2
12	1C	1	-------	96.6	1 of 1	-------	93.1	1 of 1
13	5A	2	99.4 - 102.9	101.2	0 of 2	97.1 - 100.5	98.8	1 of 2
14	5A	1	-------	103.2	0 of 1	-------	96.2	1 of 1
			Grand Average = 96.5%			Grand Average = 95.0%		
			S_{Ave} = 2.98%			S_{Ave} = 2.94%		
			Range = 89.5% - 103.2%			Range = 91.1% - 98.8%		

86.8 to 103.4 percent with a mean of 96.5 percent.

Forty-one lots were measured on ten projects. Four of these projects averaged over 100% of the Test Strip density, while the remaining six were lower than the 98% minimum recommended by ASTM D2940 (2)*. Tested at the 95% confidence level, over half of the lots were found to be significantly lower than their corresponding Test Strip. In general, then, the densities obtained on the tested projects do not compare favorably to the achievable density indicated by the Test Strip. It seems apparent that lot areas generally were not as carefully controlled with respect to moisture and number of passes as the Test Strips were.

5.2.5 Comparison of Lot Densities to Laboratory Densities:

When compared to the standard Proctor established for the Test Strip material, the average of the lot densities for all projects is 95.0 percent. The averages of each project range from 91.1 to 98.8 percent. In only one of forty-one cases did the lot density reach the recommended 100 percent of the standard Proctor. It is possible that this failure to achieve the recommended densification level may have resulted from a single Proctor density being applied to too large an area of subbase. The gradation or other material characteristics may have changed. If this were the case, however, one would similarly expect at least a few occassionally high density results from gradation changes.

5.2.6 Comparison of Lot Densities to Present Specification Densities:

The mean percent of Proctor density for all the lot densities (95.0) is significantly higher than the mean percent Proctor for the projects with the present specification (92.5). The measure of significance is again the student's "t" test at the 95% level. This

*This minimum reflects a two percent allowable for random sampling error to protect the contractor.

finding implies that the Test Strip Method yields improved densities compared to the present specifications, even in the areas that are not as controlled as the Test Strip.

5.3 Additional Laboratory Testing:

Figure 4 illustrates the variability in Proctor densities for different gradations of New Jersey's subbase materials. By holding the gradation constant on all other sieves and varying the percent passing the #4 sieve within the specification limits, it is verified that New Jersey's subbases behave similarly to the soils of other agencies as previously illustrated in Figure 2. Considering this fact, then, it is obvious that one Proctor value cannot be held as a density standard for an entire project if the percent of #4 material varies. Project files show that indeed the #4 gradation does vary over a wide range and that materials from some sources, in fact, are capable of spanning the entire allowable range (Figure 5). This range is quite wide and could result in large differences in density. It is to be noted that the suggested subbase gradation of ASTM D2940 limits the #4 sieve band for subbase to ±10 percent. This smaller band is designed to yield smaller Proctor differences.

To illustrate the influence of gradation on achievable Proctor values suppose that three different gradations were taken on the 5A material shown in Figure 4 and the percentages passing the #4 sieve were 30, 45, and 55. The corresponding optimum densities from the plot are 135.5, 137.5, and 134.8. Therefore, holding any one of these densities constant for a project would be unfair to the other locations with different gradations and, therefore, different achievable Proctors.

Another factor which could influence achievable Proctor densities is differences in specific gravity for the coarse and fine fractions

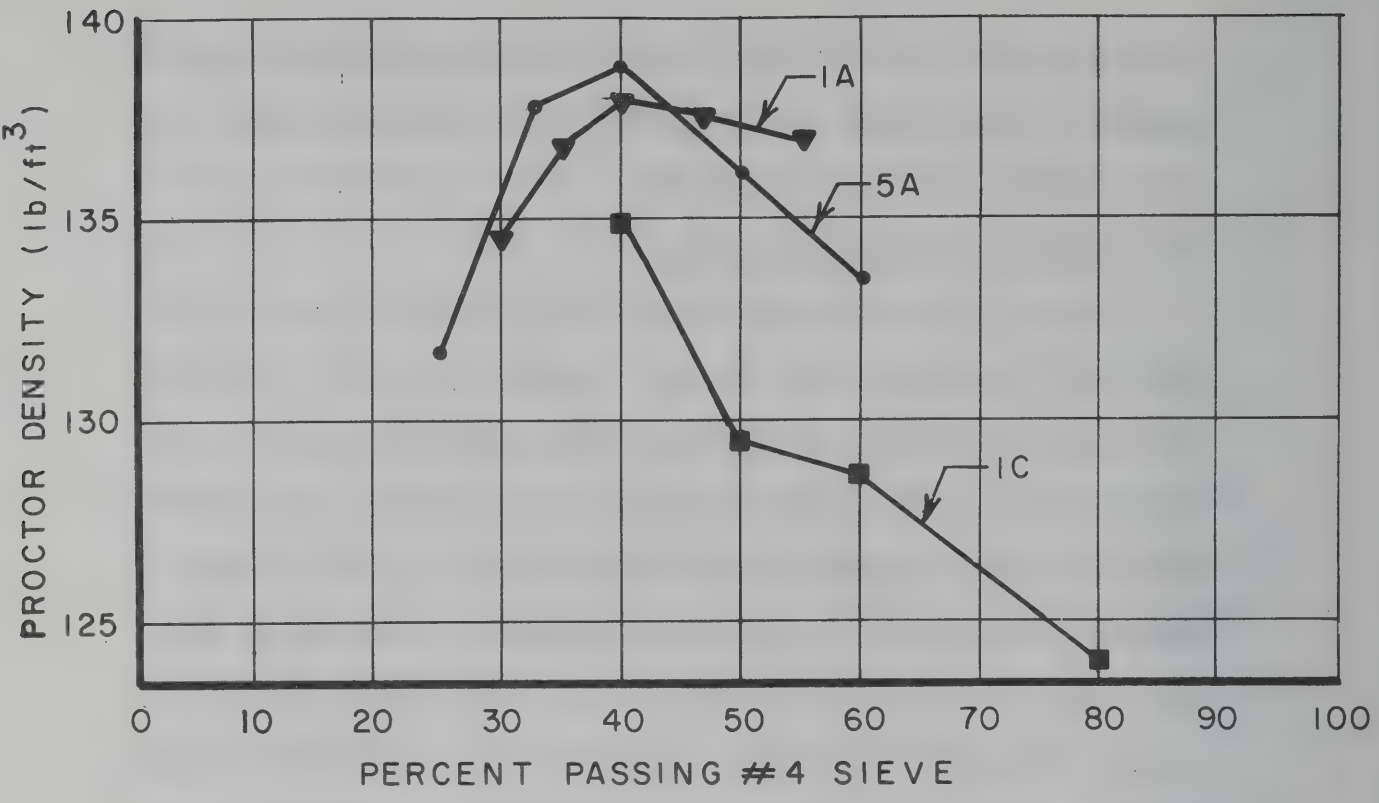

Figure 4: Relationship Between Gradation And Proctor Density For New Jersey Subbases.

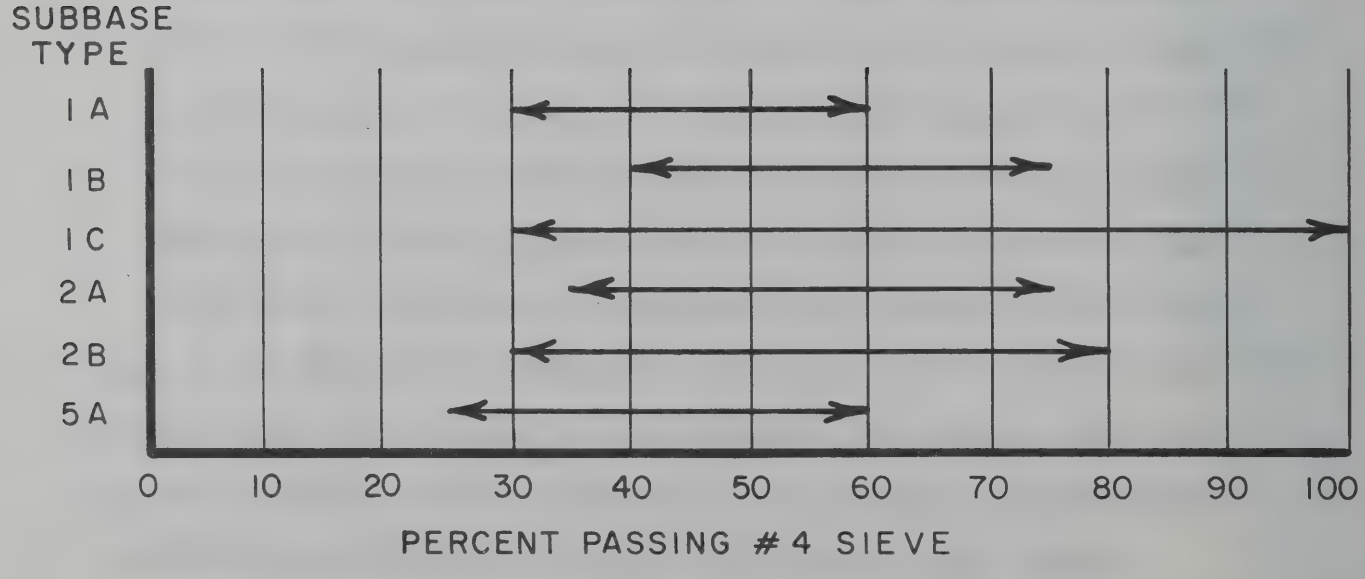

Figure 5: Allowable Subbase Gradation

of subbase. For this research the replacement procedure was used for all Proctor tests and one series of vibratory tests. To maintain the same percentage of coarse aggregate for the laboratory test as for the field gradation without actually including the larger particles which could cause significant edge effects in the small molds which are used, the 3/4" to 2" material is replaced with the No. 4 to 3/4" material. As field gradations change laboratory gradations change correspondingly regarding proportions of coarse and fine aggregates for the Proctor and vibratory tests. If the specific gravity is equal or nearly equal for both fractions of a sample, any combination of these fractions would yield an unaffected Proctor result. However, if the specific gravity for the coarse fraction varies greatly from the fine fraction, every time the proportions are changed the resulting Proctor is influenced by these values.

To explore the extent to which specific gravity can influence Proctor densities two samples of subbase (Type 1A and Type 5A) were divided into coarse and fine fractions and a specific gravity test was performed on each fraction. The specific gravities on the 1A subbase fractions were nearly equal while the specific gravities for the 5A subbase were 2.73 for the plus 4 material and 2.65 for the minus 4. Making some basic assumptions, calculations show that this difference could influence the resulting Proctor densities when performed with different proportions of coarse and fine material. In fact, a Proctor difference of almost 2 lb/ft^3 can be calculated by using the extremes of the #4 gradation range. From this limited sampling it is not known whether or not variability in specific gravity is an important factor in determining the achievable Proctor

density on New Jersey's subbases, but it is a possibility.

6.0 ESTIMATED TESTING WORKLOAD ASSOCIATED WITH THE TEST STRIP METHOD:

6.1 General:

While the desirability of adopting the Test Strip Method is related to adequate compaction results, the feasibility of this method is related to the work load. The amount of work involved is directly dependent on the number of Test Strips and lots which must be performed on each project.

Listed below are the several proposed criteria for establishing a new Test Strip for the method under investigation.

1. A different roller is used.
2. A change in the source of material.
3. A change in material lift thickness.
4. A significant change in material gradation from the same source.
5. The maximum of 10 lots for a given Test Strip has been reached.

The following discussion will be directed toward the points listed above in an effort to estimate the possible number of Test Strips that could be performed on one project.

6.2 Materials and Equipment Variability on New Jersey Projects:

First, most construction projects have more than one roller on the site and many times these rollers are not the same make and model, thus necessitating a Test Strip for each roller used. In fact, during this research a change in rollers was the most common reason for acquiring data from only a few lots from each project.

The second most common reason was a change in the subbase source. In this regard, recent records of New Jersey construction projects

indicate that the average number of sources from which one subbase type may be supplied to a project is four -- not including any blending of materials as is commonly done.

Third, the plans of recent construction projects show an average of two different thicknesses for every type of subbase. Only Type 1A material had one thickness specified on the projects where it was used. Importantly, some of the other subbase types had as many as four thicknesses on a single project.

Finally, although it has not been determined at this point what amount of change in gradation is significant, it is certain from the work done by New Jersey and others that there are changes. These changes in gradation affect the Proctor density associated with each lot. In other words, to assume that one Test Strip density applies to as many as 10 lots may be overly optimistic.

The allowable variation in New Jersey subbase soil gradations make it difficult, if not impossible, to decide when the material in a lot is no longer representative of the Test Strip material. In that light, only a change in the type of subbase will be considered as cause for a new Test Strip for this analysis of the testing work load. There are usually only two or three subbase types on a project.

Considering the points enumerated, a possible number of Test Strips that might be performed on one project include 2 for rollers, 4 for sources, 2 for thickness, and 3 for subbase types. A total of 11 Test Strips per project might be performed not including any combinations or permutations of the preceding points. If 1/2 day

is allowed to perform each Test Strip, over one week's total work is involved for each project not including the follow-up densities in the lots. Probably three engineering aides would be required to perform a Test Strip.

To estimate the work load for the necessary follow-up testing of lot densities, let us assume that a typical project is 2 miles long and a lot is 1,000 feet long. In this case the possible number of lots for one lift of subbase would be twenty (ten for each roadway). Since the lots may be completed at different times, density testing could possibly involve part of twenty separate days for two engineering aides. Considering the Test Strip Method under investigation, a project with only two lifts, one Test Strip for each, may have a total work load of over four weeks. In view of the existing limited number of nuclear gages and operators, if several projects require testing at a given time, a very significant problem would be presented. While not specifically a part of this work, an important ramification of the preceding should be noted. That is, recall that the Test Strip Method has also been recommended for embankment material. In view of the substantial work load involved for subbase which has a controlled gradation and limited number of lifts, it certainly seems possible that applications of the Test Strip Method to other more highly variable embankment materials could entail an overwhelming testing volume.

6.3 Other Considerations of Work Load:

It is possible that a Test Strip may need to be performed several times before the results can be applied to the rest of the project.

For instance, if a Proctor density is used as the target value for the Test Strip, and if the maximum density of a Test Strip is

low and the moisture is near optimum, the cause may be that the compactive effort of the roller is inadequate. In this case it would be necessary to rerun the Test Strip holding everything else constant but using a different roller.

Also, the standard specifications require all gradation acceptance testing to be done after the subbase has been rolled. Sometimes this procedure makes it necessary to perform a Test Strip over. Even though a gradation check can be made before rolling begins, there is no way to tell how much degradation may occur during rolling. Several times during this research, the material in the Test Strip broke down sufficiently to fail gradation specifications and require removal and replacement. As a result the Test Strip had to be performed again on fresh material. This is particularly common if the subbase contains some shale particles.

7.0 VARIATIONS IN TEST STRIP METHODS:

The Test Strip Method proposed for use with subbase materials in the most recent version of the new standard specifications has two major differences from the method investigated in this study. The first difference is that the proposal has no density target value for the Test Strip. There is really no way to know how adequate the resulting compaction is. For instance if the Test Strip plot of density versus number of roller passes peaks at three, this number of passes will be adhered to for the rest of the project. Suppose, however, that in actuality the Test Strip has only achieved 90% of Proctor density, which would never be known

without use of such a target density. In this instance it is doubtful that the rest of the project would achieve a much higher degree of compaction. Further, with such a low level of compaction there would be a high risk of subsequent settlement of the subbase under pavement traffic.

The second difference between the proposed and investigated methods is the lack of follow-up lot densities in the proposed method. Of course, this eliminates a great deal of the inspection work but the actual degree of compaction is unknown. To eliminate follow-up lot densities the basic assumption must be made that the characteristics established in the Test Strip do not change on the rest of the project. As has been observed this is not necessarily true. The gradation of the material certainly changes and possibly the moisture content too since there is no specification requirement. There are other factors such as roller amplitude and frequency, roller speed, and number of passes which could also influence the compaction and would be undetected without follow-up densities.

According to the proposed new standard specifications, only the dense-graded aggregate base (presently known as 5A subbase material) will have follow-up densities. All other subbase types will go untested.

8.0 SUMMARY:

This study of subbase compaction control involved the investigation of the present compaction specification and the Test Strip Method. Twenty-one sets of readings were gathered on projects controlled by the present method and fourteen projects were selected to simulate the Test Strip Method. On 10 of the latter projects, the complete procedure was followed beginning with the Test Strip and continuing

through the subsequent lot density evaluations. Also included were several standard laboratory density tests. To assist in the evaluation of the Test Strip Method, a preliminary estimate of the testing work load necessary for field personnel was made.

The following is a brief summary of the results:

1. Nearly all of the maximum Test Strip densities were less than 100 percent of the standard Proctor values. The average for all projects was 96.7 percent.

2. The averages of all forty-one lot densities was only 95.0% of the standard Proctor and 96.5% of the corresponding Test Strip densities. Over half of the lot densities were significantly lower than the Test Strip maximum.

3. The average percent of standard Proctor for projects using the present specification is 92.5. Four-fifths of these densities were significantly lower than 100 percent of the Proctor.

4. Relative to the standard Proctor values, the average subbase densities on the Test Strips (96.7%) and lots (95.0%) were significantly higher than the average from projects using the present specification (92.5%).

5. New Jersey subbase compaction could not consistently achieve 100 percent of the optimum density from any of the three standard laboratory tests performed but was closest to the standard Proctor values (ASTM D698).

6. Gradation changes produce changes in achievable Proctor densities. Therefore, one density standard should not be held constant on a project over varying gradations.

7. Maintaining subbase moisture in the field within 2 percentage points of optimum does not guarantee that the Proctor density will be achieved. However, if the moisture content is not within this range the compacted density will probably be low.

8. To evaluate the work load required to perform the Test Strip method under investigation, the complete procedure beginning with the initial Test Strip and ending with the follow-up lots was considered. For a simple hypothetical project two miles long with only two lifts of subbase and two Test Strips, the total work load could be over four weeks for field materials personnel. To evaluate the version of compaction control to be incorporated in the Department's standard specifications (i.e., eliminating lot density tests) only the work that would be encountered performing the Test Strip was considered. A fairly complicated project with several types of subbase, sources of material, rollers, and lift thicknesses could involve nearly two weeks of field work just to perform the required Test Strips. Probably three engineering aides would be required to perform each Test Strip while only two would be needed to operate the nuclear gage for any follow-up lot testing.

9.0 CONCLUSIONS:

The Test Strip Method was observed to yield improved subbase compaction compared to the present method of control. Neither method, however, consistently achieves 100 percent of the standard Proctor value which literature indicates is necessary to prevent further subbase densification under traffic.

The standard Proctor (ASTM D698) is the most appropriate laboratory test for density comparisons on New Jersey subbase for the following reasons. The two other laboratory tests investigated,

modified Proctor and relative density (ASTM D1557 and D2049 respectively) generally yield higher even less achievable maximum densities than the standard Proctor. In addition, the maximum densities for the standard Proctor and relative density tests correlate. Finally, the standard Proctor is relatively easy to perform compared to the modified Proctor and involves less expensive and more portable equipment than the relative density test.

New Jersey's subbase is capable of spanning the entire wide gradation band of the specification. Because the gradation range is so broad, a density standard should not be used for compaction control unless the standard is monitored continually to reflect these changes in gradation.

A large amount of field work is involved with the Test Strip and follow-up lots in the investigated Test Strip Method. It is estimated that over one month's actual field time could be required on even a simple project. One can reasonably expect that the amount of work involved for embankment material would be much greater than for subbase which is a controlled material. Even for the simplified Test Strip Method proposed for most subbase types in the Department's standard specifications a considerable amount of work is involved, possibly over one week for three engineering aides on a fairly complicated project. If Type 5A subbase was included in the project more than a three fold increase in this latter estimate would result for at least two engineering aides because of the need for follow-up lot density evaluation.

Keeping the subbase moisture within two percentage points of

optimum did not guarantee attainment of Proctor density. However, not staying within this range almost always yielded deficient densities.

10.0 RECOMMENDATIONS:

1. Based on the results obtained in this research, the Test Strip Method using nuclear moisture density equipment for testing yields improved compaction results compared to the presently used method specification. It is therefore, recommended that the Department adopt the Test Strip Method for all subbase materials (including Type 5A) as detailed in the pending new standard specifications with one significant addition. The maximum Test Strip density should attain some high percentage of the standard Proctor density for the material under consideration. A value of 95% seems reasonable based on the densities achieved during this research, i.e., an average lot value of 95% and an average Test Strip density of 96.7%. Although it appears that the 95% requirement would have had a high failure rate (4 of the 14 Test Strips in this study), three of the four which did not meet this density requirement also did not meet the moisture requirement. In effect, then, only one failed without a known cause. By adding this 95% criteria to the proposed specification the degree of compaction will be known for the controlled section and assumed to be adequate for the remainder of the project where the same conditions prevail.

2. To assure uniformity and a high degree of compaction throughout a project, it is most desirable that follow-up acceptance testing be performed. However, because this procedure places such excessive time demands on inspection forces, its use is not practical for all subbase types, especially when one considers the limited personnel

and equipment available at this time. It is therefore recommended that a requirement for follow-up density testing only be applied to dense-graded aggregate base course (Type 5A materials). The requirements of the pending new standard specifications are consistent with this recommendation. Since the uppermost unbound layer underlying bituminous concrete pavement consists of Type 5A material, adherence to this recommendation should result in more uniform support for flexible pavements.

3. Regarding the layer of subbase directly underlying concrete pavement, it is suggested that follow-up density testing be postponed until the results of two other research studies are completed. Both studies, "Permeability of New Jersey Subbase" and "Improved Drainage and Frost Action Criteria for New Jersey Pavement Design," are concerned with water in the subbase layers which could cause pumping and deterioration of concrete pavements. Since density has an influence on permeability, density controls will again be considered for subbase at the completion of this research.

4. In conjunction with the follow-up lot densities it is recommended that a statistically sound sampling plan be established; the new standard specification unfortunately makes no mention of sampling criteria. As a part of this sampling plan, it might be to the Contractor's advantage to decide when he would like to put an area of subbase to test since an added increase in compaction can result if follow-up measurements are taken after construction traffic has been allowed on the subbase. However, if the traffic is not evenly distributed, the variability in density across the surface can increase and provide uneven pavement support. To limit these variations, it is recommended that an evaluative procedure be

adopted using Q_L calculations similar to the thickness specification for bituminous concrete presently in use (based on Military Standard 414). In this type procedure not only the average magnitude is taken into consideration but also the variability.

5. Since the nuclear moisture-density gage is an integral part of the Test Strip Method, it is recommended that the calibration and operation procedures for this equipment be made uniform throughout the state. An effort towards this end has already begun by the Division of Research and Development and the Bureau of Inspection and should be completed as soon as possible for application. Also, a new, more dependable moisture calibration block should be obtained which will make the calibration more dependable and the nuclear gage measurements more accurate.

6. Based on the results of this research, it is apparent that monitoring the moisture content of subbase during compaction is necessary not only for the Test Strip but also during compaction of the entire project. Generally, when the moisture is not within two percentage points of the optimum, the degree of compaction achieved is significantly lower than the standard Proctor density. It is recommended that the moisture condition be under constant surveillance by the inspection forces and the moisture content kept within two percentage points of optimum. In this regard it is suggested that the Department's Design Unit consider reinstituting the ± 2 percent moisture criteria as a formal specification requirement.

11.0 RECOMMENDATIONS FOR ADDITIONAL RESEARCH:

In this report it was speculated that the amount of work involved in performing Test Strips on embankment material could be overwhelming.

The Test Strip Method is currently listed in the upcoming standard specification as an optional means for controlling embankment compaction. It is suggested that the Method's initial use be monitored as a feasibility assessment since no research has been performed on embankment materials.

Also, if New Jersey gradations and material characteristics should change sufficiently to detrimentally affect the results of comparing lot densities to the Test Strip maximum, perhaps the voids approach to compaction control mentioned in this report should be investigated. This method is independent of material changes and relates field density to Proctor density.

12.0 IMPLEMENTATION PLANS:

The use of a Test Strip has already been included in the pending new standard specifications for control of subbase compaction. A proposal to add a 95% standard Proctor density requirement to the Test Strip specification will be submitted to the Bureau of Special Engineering by Research for acceptance.

Follow-up density testing has also been adopted in the proposed specifications but only for Type 5A subbase. As an integral part of density acceptance testing, a sampling plan must be established that will determine when and how the testing shall be done. The Division of Research and Development will assist the Bureau of Plant and Project Inspection in preparing a statistically sound sampling plan to be included in the forthcoming specifications.

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APPENDICES

APPENDIX A

RELATIVE DENSITY RESULTS

Because the relative density test simulates the type of compaction induced by a vibratory roller, it was thought to be a more representative test than the Proctor tests which use impact for the compactive effort. However, the equipment is more expensive than the Proctor equipment and less portable.

If it could be determined that there is a linear relationship between the standard Proctor results and the relative density values, then, one test is merely a measure of the other. The standard and modified Proctor testing performed for this research used the replacement methods for proportioning fine and coarse aggregates, i.e., + 3/4" stone is replaced with No. 4 to 3/4" aggregate. Also following the ASTM methods for testing, however, the vibratory relative density tests use the sample in its original gradation. It was not known whether replacing the + 3/4" coarse aggregate for one test and not for the other would influence the relationship or not. Therefore, each vibratory test was performed with the original gradation and with a replaced gradation for each sample. The results of all density tests are shown in Table A-1.

To determine if a relationship existed between the results of the two laboratory tests, relative density results were obtained for 10 of the 14 Test Strip projects. Including the lots from each of these projects there were 44 field density values. When the corresponding percent standard Proctor and percent relative density (using original gradations) are plotted for these field values, a

TABLE A-1: COMPARATIVE DENSITY RESULTS

FOR DIFFERENT LABORATORY TEST METHODS

				Relative Density Results			
				Original Gradation		Replaced Gradation	
Project Number	Subbase Type	Standard Proctor	Modified Proctor	Minimum Density	Maximum Density	Minimum Density	Maximum Density
1	1A	134.15	139.5	111.64	143.87	109.60	141.21
2	1A	133.7	-----	------	------	------	------
3	1B	127.50	130.6	106.02	131.61	105.31	132.13
4	1B	130.60	131.5	112.05	139.37	114.61	140.56
5	1C	136.25	140.3	121.55	145.8	119.71	141.12
6	1C	133.25	139.5	117.97	139.07	118.08	142.21
7	1C	123.85	129.8	118.4	136.8	115.21	134.76
8	1C	125.57	124.0*	114.81	130.70	113.89	130.56
9	1C	131.80	135.5	117.36	143.60	120.43	143.11
10	1C	129.7	139.3	------	------	------	------
11	1C	104.7	130.5	------	------	------	------
12	1C	134.0	138.0	------	------	------	-------
13	5A	122.50	132.5	102.60	129.95	103.88	132.77
14	5A	136.85	139.5	112.77	148.77	116.04	142.53

*This is a single value not an average of several tests.

linear regression is observed as shown in Figure A-1. The indicated relationship is "Good" and the correlation (r) is "Highly Significant."

When the same field data is plotted with the percent standard Proctor against the percent relative density using the replaced gradations this time, a similar relationship exists. The differences between the regression lines using the original and replaced gradations is as follows.

	Original Gradation	Replaced Gradation
Regression Equation	Y = 88.68 + 0.154X	Y = 88.70 + 0.145X
Correlation Coefficient	r = 0.859	r = 0.828
Standard Error of Estimate	Syx = 1.894	Syx = 2.074

As can be seen from the preceding, both gradation methods yield essentially the same relationship. The replaced gradation has a slightly higher standard error of estimate (Syx) which implies a little more scatter about the regression line than that for the original gradation. The correlation coefficient, though, continues to show a good relationship and is still highly significant. For the present data the most one gradation method's percent standard Proctor value might differ from the other is 1/2%.

Using the ten Test Strip relative density results for the original gradation from the Test Strips, a family of curves was established relating various percentages of the relative densities to the standard Proctor densities as shown in Figure A-2. Above 30% relative density, the fit of the regression line increases from "Fair" to "Very Good" and the correlation increases from "Fair" to "High" significance. The best relationship is at the 100% relative density level. In addition, when all the field data is plotted in this form the relationship shown in Figure A-3 is observed. When this curve is added

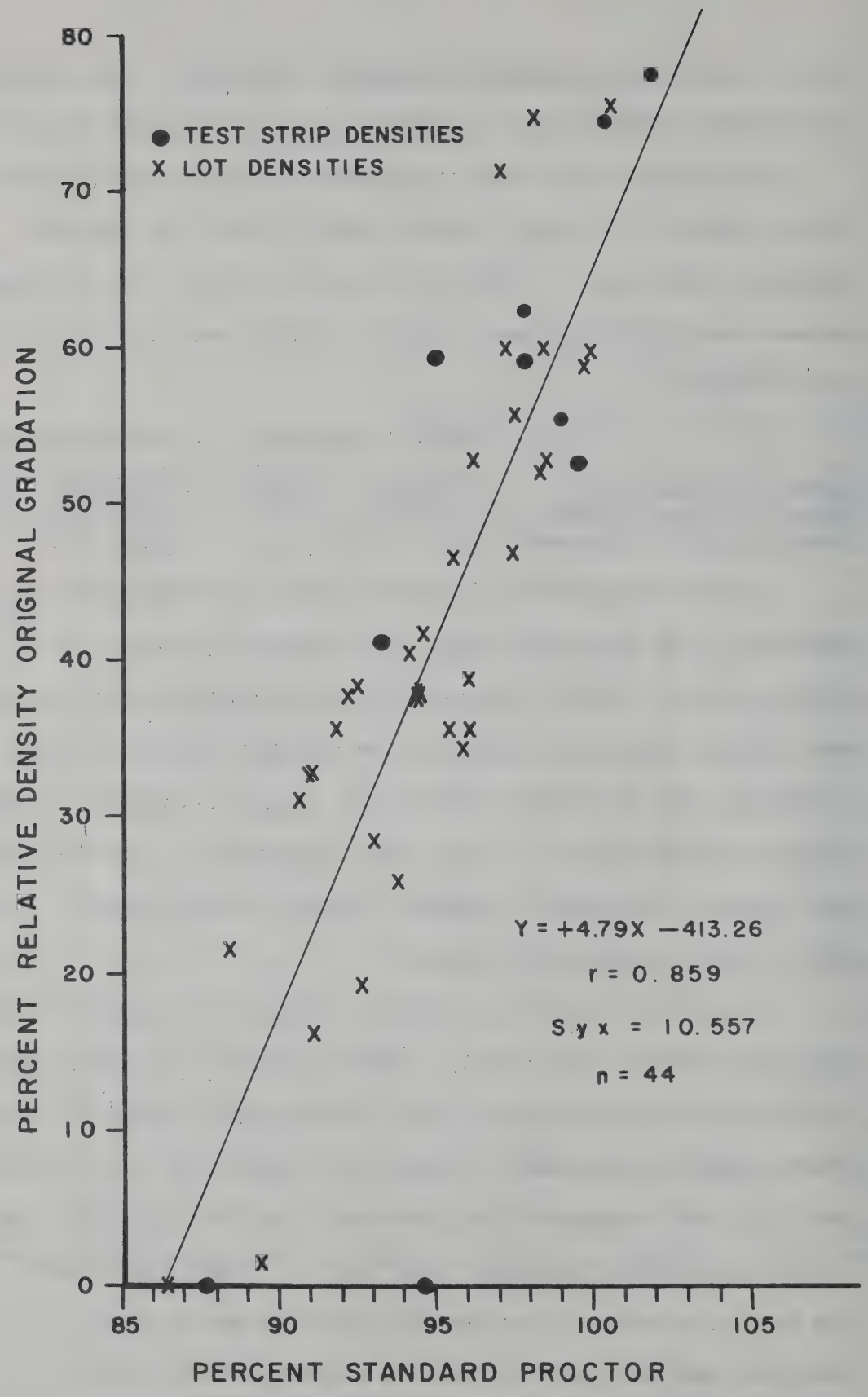

FIGURE A-1: Relationship Between Percent Relative Density Original Gradation And Percent Standard Proctor

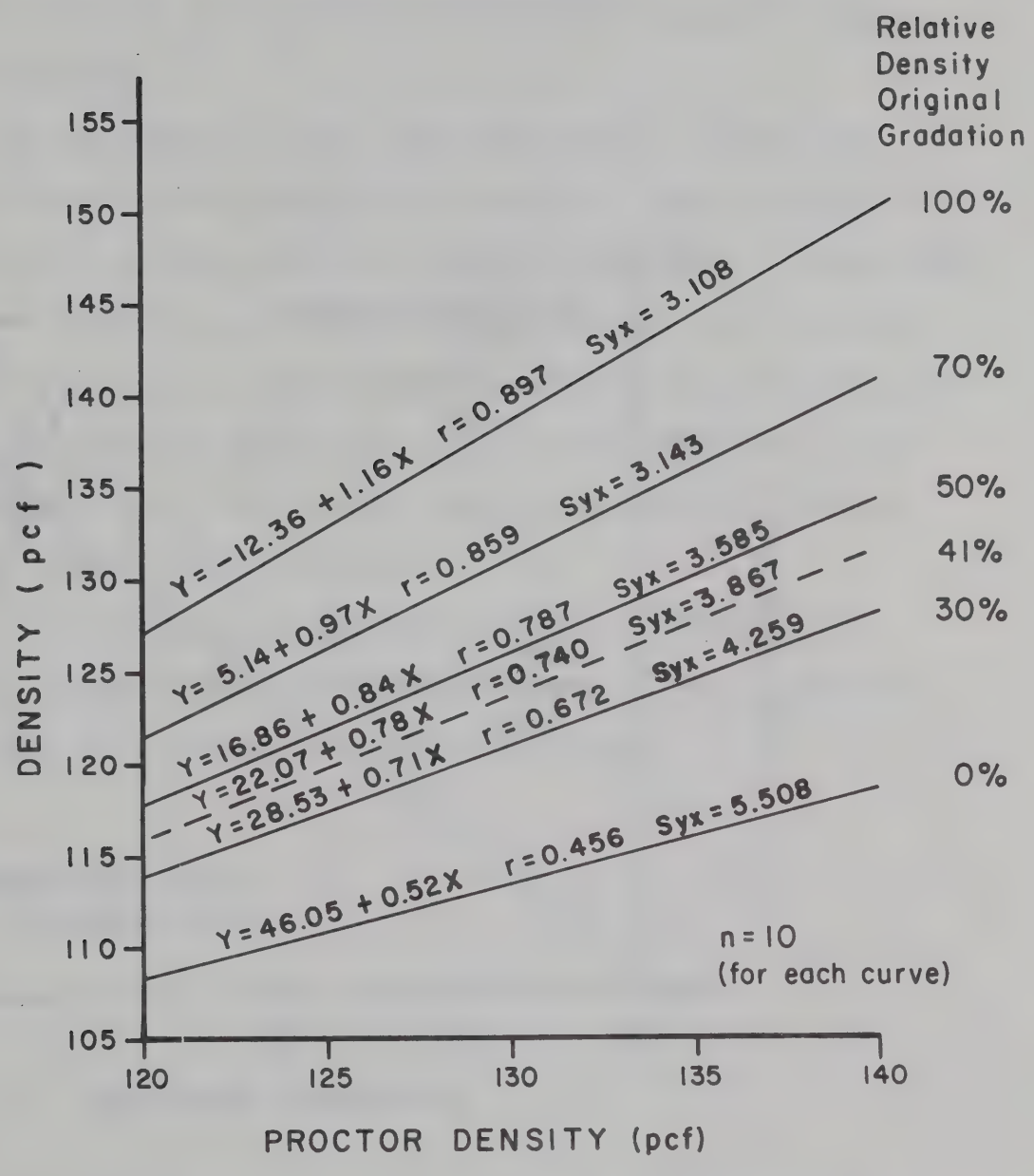

FIGURE A-2: Family Of Curves Relating Several Percentages Of The Relative Density Original Gradation With Proctor Density

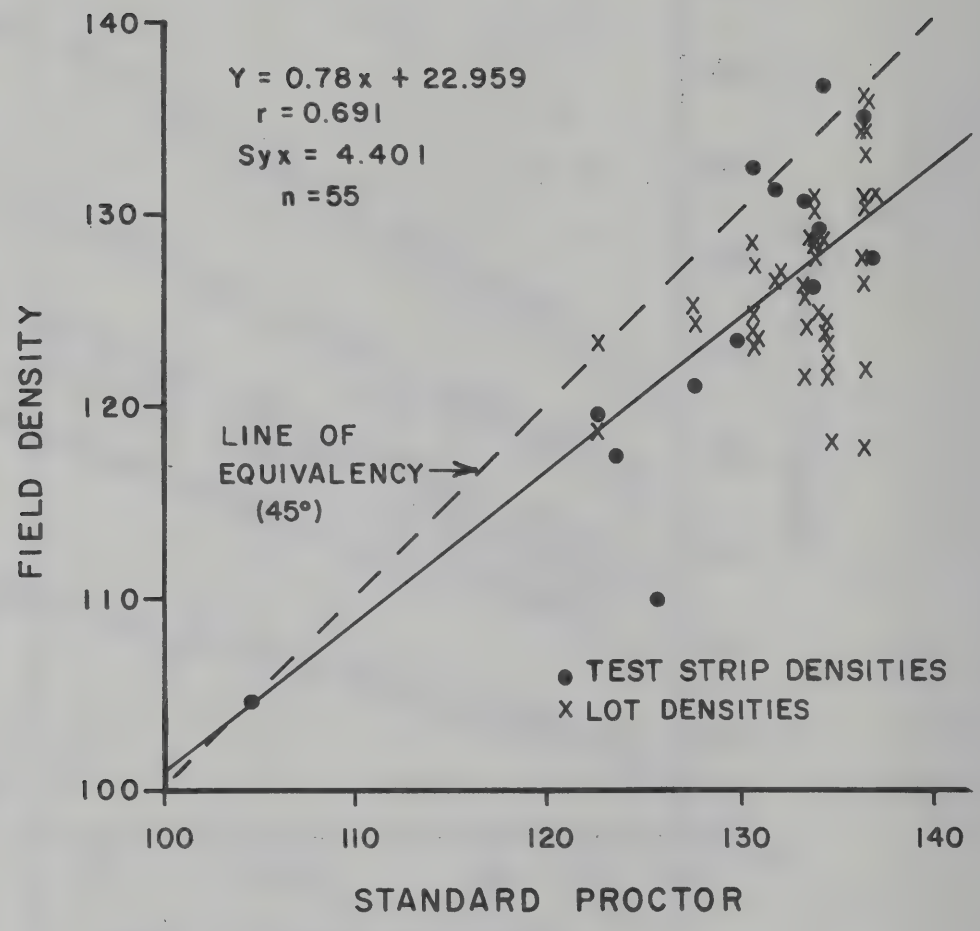

FIGURE A-3: Relationship Between Field Density & Standard Proctor

to the family of curves, it appears as the 41% relative density level. Forty-one percent is the average relative density value for all field values.

The same family of curves was established for the relative density results using the replaced gradations. The relationship is similar for both the original and replaced gradations. The variations in slope could produce differences in density from 0 pcf to 4.3 pcf for tne two different gradation methods. The largest differences are at the 100% relative density level at the higher densities of the data range which, in fact, mean a maximum 2.9% density difference between the two gradation methods.

It is therefore concluded that there exists a relationship between the standard Proctor and relative density tests regardless of whether the gradation is original or replaced.

APPENDIX B

LABORATORY VARIABILITY

The only data available to determine the variability of laboratory density tests on New Jersey subbases by Department employees was obtained during this research. The standard Proctor test was performed by at least two groups for sixteen different soil samples on a variety of subbase types. By pooling the variances of these data a standard deviation was established for the repeatability of both density and moisture for this test. The observed variability for density was 2.22 pcf and for moisture, 1.07 percent.

The modified Proctor was performed by two groups on only four different soil samples. By pooling variances the standard deviation for density is 1.65 pcf and for moisture it is 1.03 percent.

The variability of the maximum relative density test was established with limited data. Only one soil sample was tested repeatedly four times. The resulting standard deviation was 1.02 pcf.

APPENDIX C

NEW JERSEY SUBBASE MATERIALS

FROM TABLE 36: SOIL AGGREGATES, GRADATION

Types	1			2		5
Class	A	B	C	A	B	A
Sieve Size	Percentage by Weight Passing Square Mesh Sieves					
4"	100		100			
2 1/2"						100
2"	70 - 100	100		100	100	
3/4"	50 - 95	65 - 100	60 - 100	70 - 100	70 - 100	55 - 90
No. 4	30 - 60	40 - 75	30 - 100	35 - 75	30 - 80	25 - 60
No. 50	5 - 25	5 - 30	5 - 35	15 - 30	10 - 35	5 - 25
No. 200	0 - 7	0 - 7	0 - 5	*	*	3 - 12

*If the total of shale, slate, schist and soft and decomposed aggregate be 5 percent or less, the schist and soft and decomposed aggregate be 5 percent or less, the quantity passing the No. 200 sieve shall be not less than 4.5 percent and not more than 12 percent. If the total of shale, slate, schist, and soft and decomposed aggregate be more than 5 percent but no more than 25 percent, the quantity passing the No. 200 sieve shall be not less than 4 percent and not more than 9 percent. The amount of shale, slate, schist and soft and decomposed aggregate shall not exceed 25 percent.

Composition of Soil Aggregates:

Type 1 shall consist of bank run sand and gravel, commercial sand and gravel combined or blast furnace slag.

Type 2 shall be hard durable gravel mixed with sand and silt-clay so that it can be compacted into a hard, dense mass.

Type 5 shall consist of quarry-processed stone or blast furnace slag. The portion passing the No. 40 sieve shall be nonplastic according to AASHO T-91. The material passing the No. 4 sieve may consist entirely

or in part of natural or processed sand.

Typical Usage:

All subbase types are generally used in six or eight inch thicknesses for mainline paving.

Type 1A is generally used as a North Jersey top course subbase under concrete pavements.

Type 1B is usually used in South Jersey as a bottom and/or top course subbase. As a top course it underlies concrete pavements.

Type 2A is typically used as a top course subbase in South Jersey under bituminous concrete pavements. It is called road gravel, primary.

Type 2B is also used as a top course subbase in South Jersey under bituminous concrete pavements. It is called road gravel, secondary.

Type 5A is used as the top course subbase underlying bituminous concrete pavements primarily in North Jersey. It is also called dense-graded aggregate base course or quarry processed stone.

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